

A Preliminary Assessment of the Polar Ice Prediction System

Michael L. Van Woert

Walter Meier

Cheng-Zhi Zou

Tony Beesley

Phil Hovey

Cheryl Bertoia

National Ice Center

Federal Office Building #4, Room 2301, 4251 Suitland Road

Washington, DC 20395

Abstract-The National Ice Center relies upon a coupled ocean/ice model called the Polar Ice Prediction System (PIPS) to provide guidance for its 1-7 day sea ice forecasts. Here we present results on the forecast skill of this system for the highly variable month of May 2000. In this study we use a “threat index” patterned after methodologies used for tornado forecasting to assess changes in ice concentration. Specifically, the question was asked: does PIPS correctly forecast ice-free ($C < 15\%$) and ice-covered ($C > 15\%$) regions? SSM/I satellite data and other remotely sensed products are used to establish the skill score. In contrast to persistence, which has a skill of only 40-50%, it was found that PIPS correctly forecasts these situations ~90% of the time.

I. INTRODUCTION

Maritime operations in ice-covered waters require accurate forecasts of ice conditions for planning purposes. Currently the National Ice Center (NIC) uses the Polar Ice Prediction System version 2.0 (PIPS) to aid in short-term forecasting. The goal of this study is to evaluate the skill of this forecast model using satellite-derived sea ice data and NIC weekly ice analyses. We focus in this study on the melt season (May 2000) as it is a time of rapid sea ice change and hence should give one of the clearest indication of the models forecast skill. In the next section, background on the PIPS model is provided along with descriptions of the initialization and forcing fields. Section III provides preliminary results on PIPS forecasting skill for sea ice concentration. Section IV provides a brief discussion on the implications of these results from the perspective of operational sea ice forecasting and a summary.

II. PIPS DESCRIPTION

NIC relies heavily upon PIPS version 2.0 for guidance on its short-term sea ice forecasts. The model was developed at NRL Stennis Space Center [1] and runs operationally at the U.S. Fleet Numerical Meteorology and Oceanography Center (FNMOC) in Monterey, California. PIPS is a coupled, ice/ocean forecast system. A diagnostic, 15-vertical level, baroclinic Bryan-Cox ocean

model [2], provides the oceanic forcing. It uses the Navy bathymetric database and is initialized using monthly temperature and salinity from the Levitus [3] climatology. The ocean model is coupled to a dynamic-thermodynamic sea ice model [4]. Oceanic forcing is incorporated into the forecast system in the form of monthly mean ocean currents and heat fluxes from the coupled ice/ocean model [5]. Atmospheric forcing is provided by the Navy Operational Global Atmospheric Prediction System (NOGAPS), which provides weather forecasts out to 120 hours [6]. The grid resolution of PIPS is 0.28° , which varies from 17 to 33 km depending upon the location of the grid-square within the spherical coordinate system. The final output is converted to a fixed 18 km x 18 km grid.

The PIPS forecast system is initialized daily ($T=000$ hours) using a sea ice concentration analysis field derived from the Special Sensor Microwave/Imager (SSM/I) [7]. The sea ice concentration field is estimated using the Navy Cal/Val algorithm [8] and projected onto the PIPS grid using a “drop-in-the-bucket” averaging scheme. Regions with missing data, such as near the pole, were estimated by interpolation from nearby points, thus providing daily hemispheric analyses. The valid range for both the initialization and forecast fields is 0 to 1.

III. FORECAST SKILL ASSESSMENT

Forecasting sea ice concentration is analogous to the problem of forecasting the atmospheric temperature field in weather models. To assess the forecast skill of PIPS, the ice concentration changes at 024, 048, 072 and 120 hours were compared to “truth”, which for consistency, was taken to be the Cal/Val sea concentration analysis field ($T=000$) at the valid-time of the forecast.

The “threat index” [9] is a method of assessing the forecast skill of binary “events”. These statistics have been used to evaluate the forecast accuracy of severe weather events such as tornadoes [10] and for validating cloud parameterizations of numerical weather prediction

models [11]. In the method, the model forecasts an event to “occur” or “not occur” and the outcome is either “correct” or “incorrect”. The results of this test are represented by a 2x2 contingency table. The first category represents times when the forecast correctly predicts an event to occur. This is termed a “*hit*”. The second category represents times when the forecast correctly predicts an event to not occur. This is termed a “*correct rejection*”. Both of these categories represent correct forecasts. The third case, termed a “*miss*”, occurs when an event takes place and the forecast model fails to predict it. The last case occurs when an event does not take place, but the forecast predicts that it should. This is termed a “*false alarm*”. The third and fourth cases represent incorrect forecasts.

Arctic sea ice is well suited to this type of analysis because the surface is either ice-covered or ice-free. However, the methodology must be altered slightly for practical use with modeled and remotely-sensed sea ice concentrations. Satellite-derived sea ice concentration products do not discriminate the ice edge precisely, first, because the relatively low resolution of the SSM/I channels used in the algorithms (25 km) limits the precision of the ice edge detection, and second because the ice concentration algorithms have difficulty discriminating thin ice from open water. Generally, the 15% ice concentration isopleth is taken to be the threshold between ice-covered and ice-free areas [12]. Similarly, sea ice models do not discriminate well between ice-covered and ice-free regions at very low concentrations. Therefore, a similar threshold must be set to differentiate between model forecasts of ice-free and ice-covered areas. Cognizant of these data limitations, the “threat index” is established in this study by testing whether the model correctly forecasts ice-free ($C < 15\%$) and ice-covered ($C > 15\%$) regions.

In the Arctic during the melt season, once ice melts, the area generally remains ice-free (except for dynamic events that advect ice into the area). Therefore, in this study, only regions where the total ice concentration is less than 30% (the marginal ice zone) are considered. Of those locations, only points where the model predicts sea ice to change or changing ice conditions are observed in the T000 analysis field are included in the statistics. This filters out regions where the ice has melted and consistently remains ice-free and the high Arctic where no change has occurred. A “threat-score” such as this is relevant to ships operating in the marginal ice zone that need to know whether there will be substantial changes in ice cover that could endanger the ship or whether the seas will be navigable.

The PIPS threat index is baselined against the threat index for a persistence forecast. The threat index for the

PIPS forecast indicates correct forecasts 88% to 90% of the time (Table 1). In contrast, persistence yields correct forecasts only 40-50% of the time. Moreover, not only does PIPS have a high degree of forecast skill by this measure, the PIPS forecast is also relatively unbiased. This means that the frequency of ice-free ($C < 15\%$) forecasts (hits + false alarms) is roughly equal to the frequency that ice-free ($C < 15\%$) conditions occurred (hits + misses). In contrast, for persistence there are about twice as many misses as there are false alarms. Thus, persistence has a bias toward misses (cases where at least 15% ice is observed but not forecast).

The threat index presented here suggests that in the marginal ice zone PIPS performs better than persistence. However, the results depend strongly on the nature of the question asked. For example, a forecast of 29% ice cover when observations indicate coverage of 16% is considered a correct forecast because both are ice-covered based on the 15% test criteria. To examine the potential error associated with choosing an absolute threshold of 15%, the question is altered to examine the forecast skill of locations that had a relative change of 5% or more. Thus, a model forecast of more than a 5% change where at least a 5% change actually occurs is considered a ‘hit’. Here, a comparison with persistence is not applicable since, by definition, there is no change in the persistence forecast. This is a useful question for navigation as it gives an indication of the model’s ability to forecast locations where the ice cover will change substantially. It is also important to note that this skill score is only testing for substantial change in the ice cover with a threshold of 5%. It does not assess how accurate the large change is. For example, a forecast change in ice cover of 40% when the actual ice cover change is only 6% is still counted as a correct forecast in this test.

Table 1. Comparison of percentage of forecast skill categories for PIPS and SSM/I Persistence for each forecast period for the question of whether there will be less than 15% ice cover. The first two categories, ‘Hit’ and ‘Correct Rejection (CR)’ are correct forecasts. The last two categories, ‘Miss’ and ‘False Alarm (FA)’ are incorrect forecasts.

Forecast	Hit		CR		Miss		FA	
	PIPS	Pers.	PIPS	Pers.	PIPS	Pers.	PIPS	Pers.
24 hrs	67.0	31.8	24.9	10.2	4.1	39.3	4.0	18.7
48 hrs	66.7	45.9	23.4	14.6	5.5	26.3	4.4	13.2
72 hrs	65.7	45.2	24.2	15.6	5.1	25.6	5.0	13.6
120 hrs	65.4	46.2	23.4	15.5	5.8	25.1	5.4	13.2

Table 2. Comparison of percentage of forecast skill categories for a change of 5% in ice cover over forecast period.

Period	Hit	CR	Miss	FA
24 hrs	84.0	6.9	0.6	8.5
48 hrs	61.4	23.2	1.3	14.1
72 hrs	62.3	21.3	1.5	14.9
120 hrs	62.2	20.4	1.4	16.0

These results again indicate that PIPS produces accurate 24-hour forecasts about 90% of the time (Table 2). There is significant drop from the 24-hour forecast to the 48-hour forecast with the percentage of correct forecasts dropping from 93.9% to 84.6%. After 48-hours the number of correct forecasts decreases only slightly. Associated with this decrease in overall forecast skill is a marked drop in the number of hits, which is compensated to some extent by a rise in the number of correct rejections. The incorrect forecasts are dominated by false alarms, meaning that the model predicts more large changes in ice cover than actually occurred. Thus, the forecast is biased. May is typically a month of melt, so most likely these changes indicate reductions in ice cover. Thus, the PIPS model appears to melt too much ice (although advection could also play a role).

IV. DISCUSSION AND SUMMARY

In this study, we have assessed the forecast skill of the Polar Ice Prediction System (Version 2.0) sea ice concentration fields for May 2000. At times, however, simply knowing whether ice conditions are likely to change significantly at some future date could provide useful planning information, independent of whether the model correctly forecasts the specific concentration value. For example, a forecast of decreasing ice concentration in the vicinity of a ship beset in ice might indicate that it could be released from the ice. In contrast, if the ice concentration is predicted to increase, one might logically begin to plan some form of a rescue operation. A “threat index” is ideally suited to assessing the skill of binary YES/NO questions such as these. Using this criteria for forecast success, and adopting a “treat score” methodology, during the month of May 2000, PIPS was found to perform better than persistence at predicting sea ice concentration changes in the marginal ice zone.

ACKNOWLEDGEMENTS

We thank Ruth Preller and Pam Posey for answering many questions regarding the development and operation of PIPS. We also we thank Dennis Conlon and Tom Curtin of the Office of Naval Research for their support of this work.

REFERENCES

- [1] A. Cheng, A. and R. H. Preller, *The Development of an Ice-Ocean Coupled Model for the Northern Hemisphere*. (Rep. No. NRL/FR/7322—95-9627). Stennis Space Center, Mississippi: Naval Research Laboratory, 1996.
- [2] M. Cox, *A Primitive Equation, 3-Dimensional Model of the Ocean*, *GFDL Ocean Group Technical Report #1*, Geophysical Fluid Dynamics Laboratory, Princeton, NJ, 1984.
- [3] S. Levitus, *Climatological Atlas of the World Ocean*, *NOAA Professional Paper 13*, NOAA, Silver Spring, MD, 1982.
- [4] W. D. Hibler, III, *Modeling a Variable Thickness Sea Ice Cover*, *Monthly Weather Review*, Vol. 108, 1943-1973, 1980.
- [5] W. D. Hibler, III, and K. Bryan, *A Diagnostic Ice-Ocean Model*, *Journal of Physical Oceanography*, Vol. 17, pp.987-1015, 1987.
- [6] T. F. Hogan and T. E. Rosmond, *The Description of the Navy Operational Global Atmospheric Prediction System's Spectral Forecast Model*, *Monthly Weather Review*, Vol. 119, No. 8, pp. 1786-1815, 1991.
- [7] P. G. Posey and R.H. Preller, "Operational Use of SSM/I Ice Concentration in the Initialization of a Coupled Ice-Ocean Model", (Rep. No. NRL/FR/7322—95-9634). Stennis Space Center, Mississippi: Naval Research Laboratory, 1994.
- [8] R. Ramseier, G. Rubinstein, and A. F. Davies, *Operational Evaluation of Special Sensor Microwave Imager by the Atmospheric Environmental Service, Centre for Research in Experimental Space Science*, York University, New York, Ontario, Canada, 1988.
- [9] R. Atlas, M. Ghil, and M. Halem, *Reply to Comment on: Time-Continuous Assimilation of Remote Sensing Data and its Effect on Weather Forecasting*, *Monthly Weather Review*, Vol. 109, No. 1, pp. 201-204, 1981.
- [10] D. B. Stephenson, *Use of the "Odds Ratio" for Diagnosing Forecast Skill*, *Weather and Forecasting*, Vol. 15, pp. 221-232, 2000.
- [11] J. A. Beesley, C. S. Bretherton, C. Jacob, E. L. Andreas, J. M. Intrieri, and T. A. Uttal, *A Comparison of Cloud and Boundary Layer Variables in the ECMWF Forecast Model with Observations at the Sheba Ice Camp*, *J. Geophys. Res.*, Vol. 105, pp. 12337-12349, 2000.
- [12] K. Steffen, J. Key, D. J. Cavalieri, J. Comiso, P. Gloersen, K. St. Germain, and I. Rubinstein, *The estimation of geophysical parameters using passive microwave algorithms*, in *Microwave Remote Sensing of Sea Ice*, Geophysical Monograph 68, F. D. Carsey, ed., American Geophysical Union, Washington, DC, pp. 201-232, 1992.